Journal of Cleaner Production 154 (2017) 389–400

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Influence of different factors in the life cycle assessment of mixed municipal solid waste management systems – A comparison of case studies in Finland and China

Miia Liikanen*, Jouni Havukainen, Mari Hupponen, Mika Horttanainen

Department of Sustainability Science, Lappeenranta University of Technology, P.O. Box 20, FI-53851, Lappeenranta, Finland

ARTICLE INFO

Article history:
Received 5 October 2016
Received in revised form
31 March 2017
Accepted 3 April 2017
Available online 5 April 2017

Keywords:
Life cycle assessment
Municipal solid waste
Sensitivity
Landfilling
Incineration

ABSTRACT

The life cycle assessment (LCA) of municipal solid waste (MSW) management systems is typically rather arduous due to extensive data acquisition needed to calculate the direct and avoided emissions of the systems. A possibility to diminish the workload of the LCA studies is to utilise default or generic data instead of direct and case-specific data. However, it is crucial to know when this is justified. Direct and case-specific data should be applied at least to the key processes and parameters which have the strongest influence on the total results, whereas default data can be applied to the processes and parameters which have only a minor influence on the total results.

Mixed MSW management systems in the South Karelia region, Finland, and the city of Hangzhou, China, were compared in this study in terms of the influence of different factors on the LCA results of the systems. The comparison focused particularly on the influence of individual parameters on the global warming, acidification and eutrophication potentials of the LCA studies. According to the study, parameters directly related to the generation and collection of landfill gas, the energy and fossil carbon content of mixed MSW, energy production efficiencies, as well as the nitrogen oxide and sulfur dioxide emissions of incineration had the highest influence on the total results in both case studies, and therefore direct, case-specific data should be applied particularly to them. The use of machinery in landfilling, the electricity and chemical consumption in leachate treatment, the transportation of auxiliary materials (e.g. chemicals and incineration residues) as well as the electricity consumption and the use of machinery in bottom and boiler ash treatment had instead only a minor influence on the total results. Default or generic data could be applied to them to diminish the workload of the LCA studies. It is worth mentioning that the findings of the study apply merely to these particular case studies. Further research and corresponding comparisons are required to draw more profound and general conclusions.

1. Introduction

Waste is a worldwide issue. Particularly due to population growth and urbanisation in developing countries, the generation of municipal solid waste (MSW) has increased significantly over the past decades. For instance, the global MSW generation rate is expected to double by 2025 from the generation rate in 2012 (World Bank, 2012). Alongside the increase in MSW generation, the environmental impacts of MSW have been more comprehensively identified globally. The growing awareness of the negative environmental impacts of MSW has increased the use of life cycle assessment (LCA) methodology in the MSW management sector. By means of LCA, the potential environmental impacts of MSW management systems can be evaluated (EN ISO 14040, 2006; EN ISO 14044, 2006). LCA enables taking into account both direct (i.e. emissions from treatment processes) and avoided (i.e. emissions avoided due to energy or material substitution) emissions of MSW management processes (Ekvall et al., 2007). Laurent et al. (2014) conducted a comprehensive review of the application of LCA to MSW management systems. According to the study, LCA was first conducted on MSW management systems in the 1990s, and currently it is a widely used method in the assessment of the environmental impacts of MSW management systems. The LCA of MSW management systems has been primarily applied in high

* Corresponding author.
E-mail address: miia.liikanen@lut.fi (M. Liikanen).

http://dx.doi.org/10.1016/j.jclepro.2017.04.023

income countries, particularly in Europe. It has also gained popularity in lower income countries during the past decade due to increased MSW generation and urbanisation. For instance, several MSW LCA studies have been conducted in China in recent years.

LCA studies of MSW management systems are typically highly case-specific, depending on the objective of the study and local conditions and features. Nevertheless, the purpose of most LCA studies is the comparison of different treatment and management options for MSW. For instance, De Feo and Malvano (2009) assessed the environmental impacts of 12 different management options for MSW in a region in South Italy to select the best MSW management system for the region. LCA has also been used to compare different source separation and collection systems: for instance, Larsen et al. (2010) assessed five scenarios with alternative collection systems for recyclables by means of LCA, and Rigamonti et al. (2009a) utilised LCA in the optimisation of collection systems for recyclables. Additionally, LCA has widely been used as a decision support tool for policy making in the field of MSW management. For instance, Turner et al. (2016) and Lazarevic et al. (2012) introduced different approaches to how the LCA of MSW management systems can be utilised as a decision support tool.

The intricacy of MSW management systems poses challenges for LCA studies. Of the main phases of LCA (i.e. goal and scope definition, inventory analysis, impact assessment and interpretation) (EN ISO 14040, 2006), particularly inventory analysis is highly time and resource-consuming due to the comprehensive data acquisition needed to calculate the direct and avoided emissions of the system. Various approaches have been developed to facilitate and simplify LCA (e.g. Fleischer et al., 2001). A simple and straightforward way to diminish the workload of MSW LCA studies is to use default or generic data (i.e. secondary data) instead of direct and case-specific data (i.e. primary data) in inventory analysis. In order to do that without reducing the reliability of the results, it is important to know the influence of an individual parameter on the total results. Therefore, the following straightforward rule of thumb should be retained: one can apply default or generic data to parameters with a minor influence on the total results while simultaneously applying direct and case-specific data to other parameters in order to maintain the reliability of the LCA study.

The influence of an individual parameter on the total results can be identified by sensitivity analysis, which assesses the effect of input parameters' changes on the total results. The more sensitive the result is to a given parameter, the more case-specific and reliable the data concerning the parameter should be. Direct data should be used at least concerning the key parameters which have the highest influence on the overall environmental performance of MSW management systems. Regarding the LCA of MSW management systems, the key processes and parameters have been rather well recognised in literature (see Table 1). The environmental impacts of surrounding systems, e.g. electricity and heat production, often override the environmental impacts of the MSW management system itself (Ekvall et al., 2007). Parameters related to energy and material recovery and substitution (e.g. electricity and heat production efficiencies, material recovery efficiency) are therefore particularly important in MSW LCA studies. While previous research has particularly focused on the key processes and parameters of MSW management LCA studies, little research has been conducted to identify the processes and parameters which have only a minor influence on the total results. Nevertheless, they are crucial in terms of the above-mentioned simplification possibility, i.e. using default or generic data instead of direct and case-specific data.

Two different case studies are compared in this study: the South Karelia region in Finland and Hangzhou city in China (see Fig. 1). South Karelia is a region in South-East Finland, and it consists of nine municipalities. Hangzhou is the capital city of the Zhejiang Province in Eastern China. In both case studies, mixed MSW (i.e. the remaining part of MSW after the source separation of different waste fractions) management system of the area is investigated by means of LCA. The case studies have been initially reported by Hupponen et al. (2015) and Havukainen et al. (2017). The comparison of the case studies focuses particularly on different input parameters used in the LCA of the mixed MSW management systems. The objective of the study is to determine the most and least important (i.e. sensitive) input parameters of the case studies in order to identify possibilities to simplify their LCA by using default or generic data instead of direct and case-specific data.

Table 1
Typical key factors in the LCA of MSW management systems presented in literature (literature studies particularly focusing on the subject are listed as references).

MSW management phase	Key factor	Reference
MSW generation	Waste composition	Slagstad and Brattebø, 2013
	Source-separation efficiency	Rigamonti et al., 2009b
Landfilling	Collection of landfill gas (LFG) and leachate	Manfredi and Christensen, 2009
Incineration	Energy recovery and substitution	Burnley et al., 2015
Recycling	Material recovery and substitution	Rigamonti et al., 2009b

The research questions are the following:

- What are the key factors, i.e. processes and input parameters, in the case LCA studies on South Karelia, Finland, and Hangzhou, China?
- Which factors have instead only a minor influence on the total results in the case areas?
- How could the LCA of the case studies be simplified by using default or generic data instead of case-specific, direct data?

2. Materials and methods

2.1. Description of the case areas

The South Karelia region in Finland and Hangzhou city in China were selected as the case areas for the study to analyse both high income and lower income countries' mixed MSW management systems (see Supplementary material A for further information). They represent distinctly different areas (e.g. population, geographical location, income level) and mixed MSW management systems, however with some similarities, which enable the comparison between them. For instance, incineration is a treatment method for mixed MSW in both areas. Since the case studies differ from each other in many respects, the similarities between them can be an indication of a more extensive phenomenon. In other words, if the influence of a given parameter on the total results is similar in both case studies, the same phenomenon can be valid in other mixed MSW management systems, too.

Key data (i.e. population, MSW generation rate, the composition of mixed MSW and collection system) concerning the case areas' MSW management systems are presented in Fig. 2. In South Karelia, all mixed MSW generated in the region was landfilled until 2013. The incineration of mixed MSW started in 2013 and has increased in stages. Currently, all mixed MSW generated in the region is incinerated. Since there is no waste incineration plant in the region, mixed MSW is transported to a waste incineration plant in Riihimäki which is located approximately 220 km from the region. (Etelä-Karjalan Jätehuolto Oy, 2016.) In Hangzhou, incineration and